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SURFACE ANALYSIS FOR SIGNS OF CORROSION OF FIXED ORTHODONTIC APPLIANCES USED IN VIVO

ABSTRACT

The objective was to evaluate and assess the surface quality of fixed orthodontic appliances after intraoral usage for several months. Nine sets of orthodontic brackets by three different manufacturers and twelve archwires differing in chemical composition were analyzed in a scanning electron microscope with an energy dispersive X-ray analyzer for signs of corrosion. Obtained results showed that the majority of the evaluated appliances displayed no traces of corrosion. Machining or casting defects hardly ever act as the origins of corrosion processes. However, some samples displayed signs of corrosion of a galvanic and pitting nature. The authors claim, that despite the surface defects, most of the appliances were able to retain the desired corrosion resistance, although in some cases these flaws could act as the origin of corrosion processes.

Key words: *corrosion, orthodontic appliances, brackets, archwires, orthodontics*

INTRODUCTION

Awareness of corrosion, which is defined as the phenomenon of inadvertent destruction of materials caused by chemical or electrochemical reaction occurring at the frontier of a material and its external environment [1,2], is one of the main topics of ongoing discussion on the alleged perniciousness of fixed orthodontic appliances. Labile components of the orthodontic appliances work environment, such as temperature, saliva, salts, liquids, medicines, food leftovers, oral bacteria and various mechanical forces arising from the proceedings of the treatment process, have a significant impact on the existence and extent of corrosive damage [1,2]. Thus it is important to select durable and at the same time corrosion resistant alloys, among which especially stainless steels, cobalt-chromium, titanium-nickel and β-titanium alloys are distinguished [3].

The oral cavity constitutes an ideal environment for analysis of the biological processes involving orthodontic appliances. Metal corrosive damage occurs by the loss of ions directly into the solution or by gradual dissolution of the surface layer, usually in the form of oxides or sulphides [2]. Dental materials constantly interact with the body fluids, which fulfil the electrolytic basis, for example, for the flow of metal ions, whereby the oral tissues are exposed to the activity of constant chemical and physical stimuli. Modifications on a microscopic level, an example of which is the release of metal ions, can cause adverse reactions which are generally referred to as metallosis.

The aim of the study was to evaluate and assess the surface quality of selected orthodontic items – brackets and archwires made of titanium-nickel, stainless steel and β-titanium alloys – after being used intraorally for several months. Their surfaces were examined using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). An attempt was also made to determine the likely causes of the damage noticed.

MATERIALS AND METHODS

The study involved the following elements:

- 9 sets of brackets from 3 different manufacturers used in vivo from 18 to 47 months;
- 12 archwires of circular or rectangular cross-section, fabricated from the following alloys: NiTi, stainless steel and β-titanium that have been in service from 3 weeks to 11 months.

A full list of evaluated specimens is presented in Table 1. Chemical compositions of selected materials are presented in Table 2.

Table 1. *List of evaluated specimens; SS – stainless steel, NiTi – nickel titanium alloy, β-titanium (TMA) – titanium molybdenum alloy*

Specimen no.	Description	Material	Time in service
1	brackets set	SS	21 months
2	brackets set	SS	30 months
3	brackets set	SS	23 months
4	brackets set	SS	18 months
5	brackets set	SS	47 months
6	brackets set	SS	28 months
7	brackets set	SS	27 months
8	brackets set	SS	31 months
9	brackets set	SS	22 months
10	archwire	NiTi	7 weeks
11	archwire	NiTi	2,5 weeks
12	archwire	NiTi	1,5 weeks
13	archwire	NiTi	2 months
14	archwire	NiTi	no data
15	archwire	SS	no data
16	archwire	TMA	11 months
17	archwire	SS	9 months
18	archwire	SS	5 months
19	archwire	SS	no data
20	archwire	SS	no data
21	archwire	SS	no data

Before observation began, each sample was rinsed from organic debris using ultrasonic cleaner filled with ethyl alcohol solution at room temperature. The specimens were analyzed in a scanning electron microscope (Hitachi S-3000N) with an energy-dispersive x-ray analyzer (EDS Thermo Scientific 4460D-1UUS-SN). Scanning electron images were viewed and photographed at 30 to 2000×. Elemental analysis was performed of the surface of 6 selected areas and 4 spots of orthodontic items. Randomized SEM photographs of the orthodontic appliances used were examined for signs of corrosion.

Table 2. *Chemical composition of selected materials. EDS results*

	Si	Cr	Ni	Fe	Ti
SS bracket	1.38	17.64	4.11	balance	N/A
SS archwire	1.04	20.56	8.27	balance	N/A
NiTi archwire	N/A	N/A	balance	N/A	45.22

RESULTS

Overall surface visual examination of the vast majority of the appliances used showed no discernible corrosive damage (Fig. 1, Table 3). Machining or casting defects were observed, but these had virtually not affected the materials' corrosion resistance (Fig. 2, Table 3). The elements mainly showed the existence of scratches caused by orthodontic instruments (Fig. 3), chipping, wear traces at the bracket-archwire contact and short shots (Fig. 2), although evaluation and assessment of some samples exhibited the presence of corrosive damage of a galvanic and pitting nature.

Table 3. *Detailed results obtained from specimens analysis*

Specimen no.	Short description	Surface analysis results
1	Brackets set	No signs of corrosion, visible numerous scratches made by orthodontic instruments
2	Brackets set	No signs of corrosion, discernible casting defect on one of the brackets and inhomogeneity of the material structure
3	Brackets set	Numerous corrosion pits at the labiate bracket wings surface
4	Brackets set	No signs of corrosion, visible numerous scratches made by orthodontic instruments
5	Brackets set	No signs of corrosion, discernible numerous cavities of unknown origin at the brackets surfaces
6	Brackets set	No signs of corrosion
7	Brackets set	No signs of corrosion, visible only machining defects as scratches
8	Brackets set	Numerous corrosion pits at the short shots, visible severe damages arising from brackets dismantle

Specimen no.	Short description	Surface analysis results
9	Brackets set	One bracket's hook marked with numerous damages of unknown origin
10	NiTi archwire	No signs of corrosion, slight surface abrasion caused by brackets-archwire contact sites
11	NiTi archwire	No signs of corrosion
12	NiTi archwire	No signs of corrosion
13	NiTi archwire	No signs of corrosion
14	NiTi archwire	No signs of corrosion
15	SS archwire	No signs of corrosion
16	TMA archwire	Numerous corrosion pits occuring linearly along the machining traces, visible rolling tracks
17	SS archwire	No signs of corrosion
18	SS archwire	No signs of corrosion, visible only linear rolling tracks
19	SS archwire	No signs of corrosion, slight surface abrasion
20	SS archwire	No signs of corrosion
21	SS archwire	No signs of corrosion

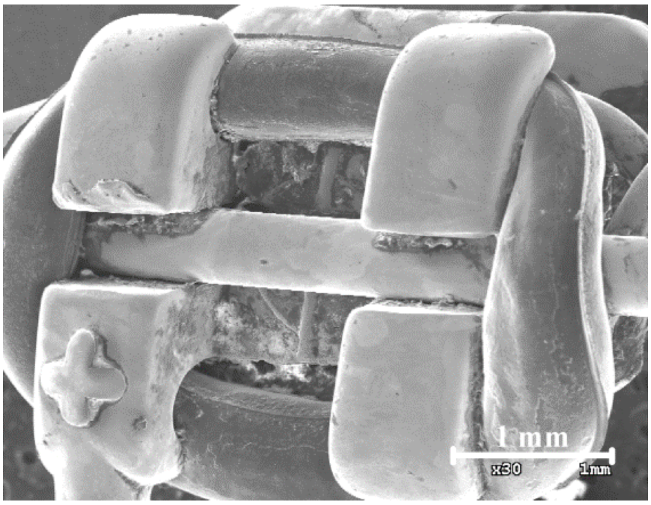

Fig. 1. Bracket from set no. 4 after 18 months of use, NiTi wire and elastomeric ligature. No discernible corrosion damage. SEM image

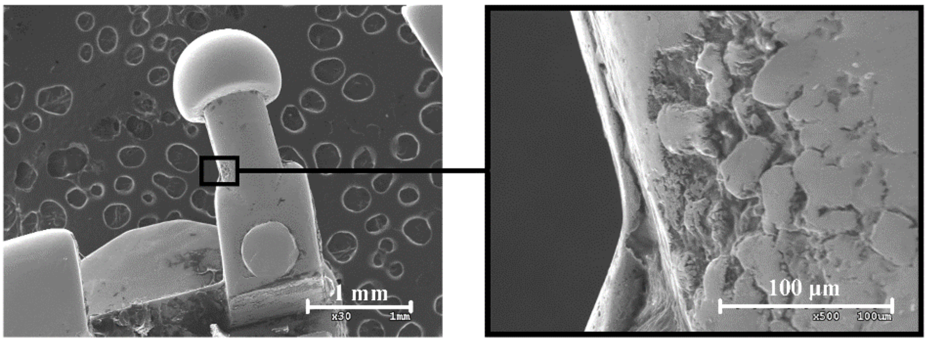

Fig. 2. Bracket from specimen no. 4 set, discernible casting defect. None corrosion damage noticed. SEM image

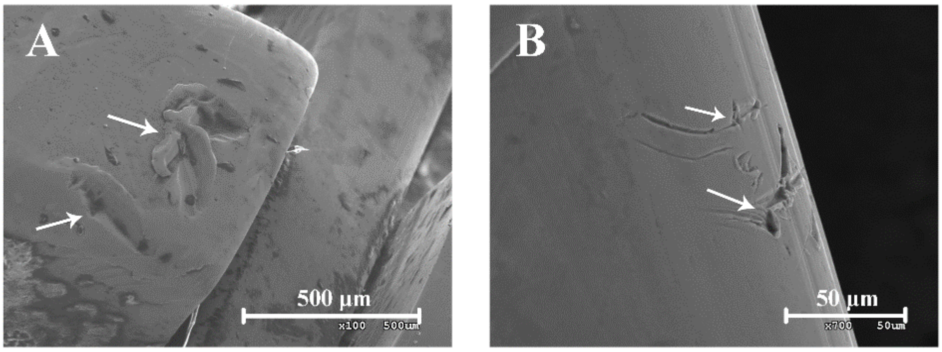

Fig. 3. Specimen no. 6 SS bracket – A, and SS archwire used for 5 months (specimen no. 18 - B). Visible sharp tool scratches (arrows). No pitting. SEM image

Traces of pitting corrosion were found on the β-titanium archwire surface that had been in service for 11 months (specimen no. 16). Linear orientation of pits occurring along the machining trace was observed (Fig. 4). Corrosion damage was also observed on one of the braces from the specimen no. 8 set after 31 months in service. Advanced corrosion damage of a pitting nature had appeared near to the casting defects (Fig. 5). To establish the plausible cause of the observed alterations, EDS analysis of the overall surface and particular points was made – the analyzed points are illustrated in Figure 6.

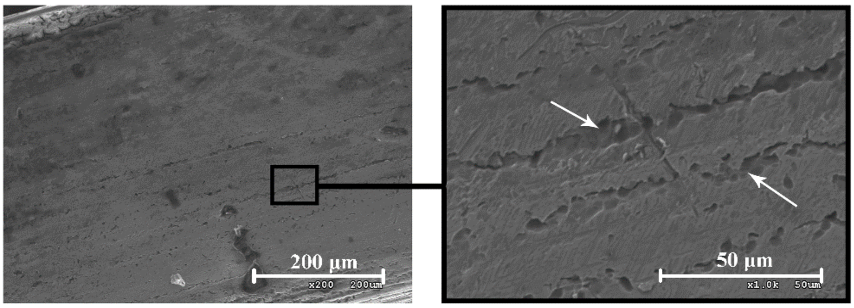

Fig. 4. β-titanium archwire surface (specimen no. 16). Discernible numerous linear surface irregularities (arrows). SEM image

According to the results, the item was cast from typical stainless steel. It is worth noting that the composition of the corroded areas (Table 4) differs remarkably from the non-damaged surface. The nickel levels are considerably lower, reaching 2% in wt% disparity. What is more, the iron and chromium amounts were raised.

Corrosion traces were also found on the brackets used intraorally for 23 months (specimen no. 3). The damage is visible only at high magnification, of the order of 2000×. The EDS analysis of these brackets suggested heterogeneity of the material, perhaps indicating a casting defect surrounded by numerous corrosion pits (Fig. 7).

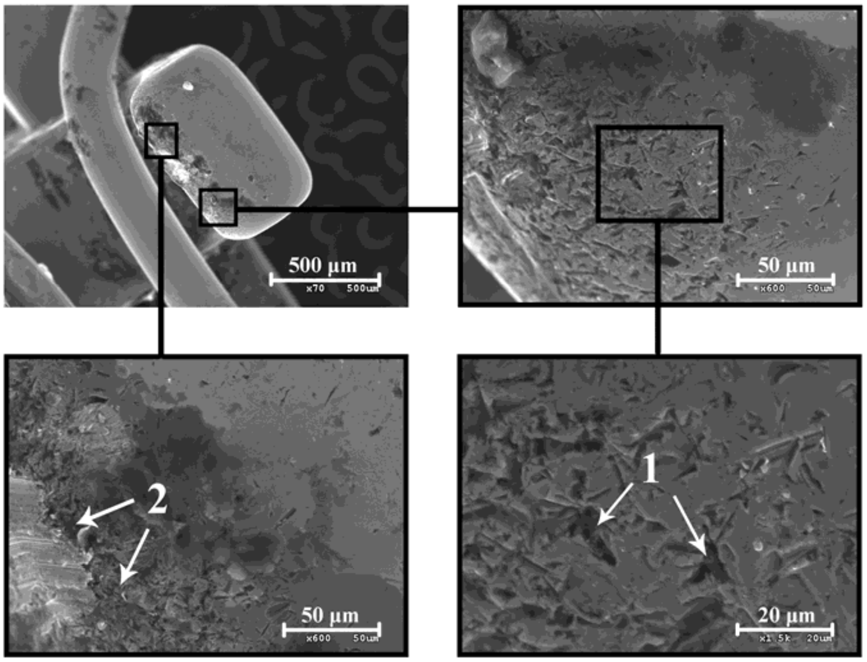

Fig. 5. Surface of bracket from set no. 8. Visible numerous surface irregularities: 1 – corrosive damages by casting defects, 2 – traces of corrosive dissolution. SEM images.

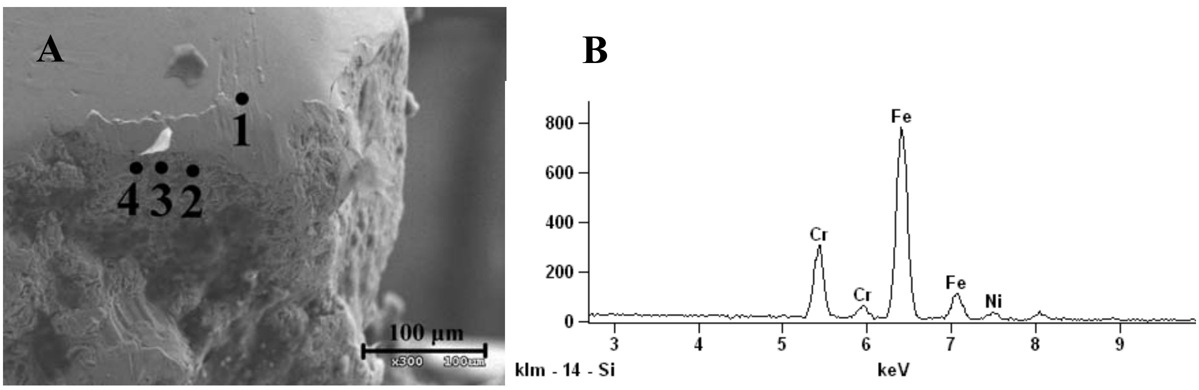

Fig. 6. Specimen no. 8 (bracket) surface: a) image of observed damage with EDS analysis spots (1-4). SEM image, b) EDS plot for pt. 4

Table 4. *Chemical composition of bracket featured in Fig. 6. EDS results*

Test point according to Fig. 6	Quantitive results (wt%)			Wt% error (+/-)		
	Cr	Fe	Ni	Cr	Fe	Ni
1	16.77	79.12	4.11	0.32	1.18	0.42
2	16.60	79.36	4.04	0.39	1.45	0.53
3	19.26	78.55	2.19	0.71	2.49	0.57
4	17.83	78.00	4.17	0.62	1.58	0.47

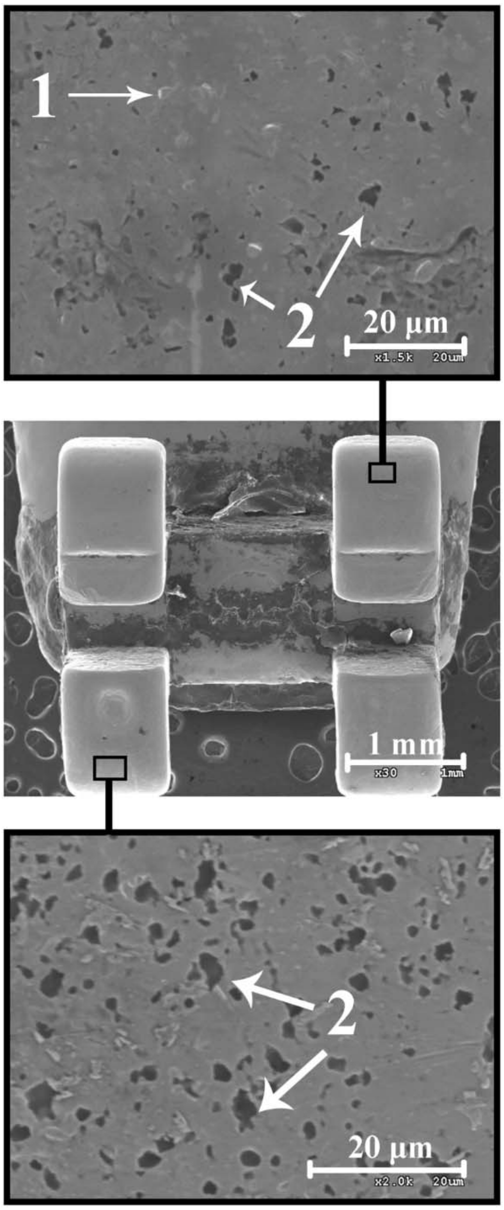

Fig. 7. Microscopic images of specimen no. 3 after 23 months in service; 1 – material structure heterogeneity, 2 – corrosion pits. SEM images

DISCUSSION

According to the results, in most cases, regardless of existing machining or casting defects, the materials used in orthodontic applications retain the desired corrosion resistance (Fig. 1, Fig. 2, Table 3). Available references state that damage caused by the orthodontic instruments and the bracket-archwire contact sites act as the preferred areas for the origin of corrosive attacks [2]. Chippings and bracket-archwire contact wear traces are the ideal locations for potential saliva, dental plaque and food debris build-up, which may result in a predisposition to the development of electrochemical or biological corrosion. However, it appears that surface defects are often too small to act as corrosion origins [4], as has been confirmed in the study (Fig. 3). The protective passive oxide layer must have been reconstructed quickly enough to continue providing the alloy with the required level of protection against aggressive intraoral environment.

Evaluation and assessment of some specimens exhibited the presence of corrosive damage of a galvanic and pitting nature.

Traces of pitting corrosion oriented along the machining trace were found on the β-titanium archwire surface that had been in service for 11 months (Fig. 4). Similar images were obtained by Grimsdottir and Hensten-Petterseri [5]. Microscopic observations of as-received products like archwires and brackets made by Eliades et al. [3] have proven that even unused appliances present excessively porous surfaces with a high susceptibility to pitting corrosion. Moreover, Bakhtari et al. [1] suggest that the method of manufacturing might be of equal or greater relevance to the susceptibilty to galvanic corrosion than the product composition. Porous surface topography contributes to an increase of brace-archwire friction intensity and can indirectly cause corrosion processes. What is more, the presence of microcraters on the product surface can lead to the deposition of microorganisms that locally acidify the surrounding environment. Local reduction of the pH level, combined with the limited amount of oxygen and ullage of saliva causes perturbation of the formation of a tight passive layer.

The different mass ratio of the alloying elements observed in the analyzed points (Table 4) may be the result of corrosive alloy dissolution and the formation of corrosion products in the oral environment, as mentioned in the Introduction. Without immersion media spectroscopic analysis such as that conducted by e.g. Eliades et al. [3], it is impossible to establish which element was the most dissolutive one, but according to the literature it could have been nickel, which is known for its ability to undergo corrosion processes resulting in release from the Ni-containing alloys [6] and its ability to bind proteins to build complete antigens [7].

A typical stainless steel used for orthodontic applications contains 8 to 12% nickel and 17 to 22% chromium [8]. However, the materials used in the assessed brackets are relatively low in nickel (4 wt%) with a retained typical chromium addition. The alloy composition is extremely important when considering mutagenicity, toxicity, cariogenicity or allergies to particular elements. The main stainless steel alloys additions, nickel and chromium, are especially known to be strong immunologic sensitizers [9,10]. Regarding the fact that approximately 10% of the general population exhibits a hypersensitive reaction to nickel [9,11], it is important to provide safe and non-corroding material. Although some authors claim that the amounts of metallic ions released in corrosion processes are relatively small, safe for the humans and unable to trigger hypersensitivity reactions [11,12], mainly because they do not exceed the recommended daily dietary intake [7,13], there are numerous published case reports on severe adverse reactions to orthodontic alloys [9,14]. Furthermore, the corrosion products of dental cast alloys have been found in saliva and in the gingiva of patients [5] and the genotoxicity of nickel and chromium has been proven [15].

CONCLUSIONS

The obtained findings allow the authors to formulate the following conclusions:

- The vast majority of the analyzed orthodontic items were not damaged by corrosion during in vivo application. This means that, despite existing machining or casting defects, the materials used in orthodontics retain their required corrosion resistance.
- Considering individual samples, corrosion damage was observed, inter alia, that had the nature of galvanic or pitting corrosion. The initiation of corrosion processes could be caused by uneven surface elements arising from the technological process. The presence of ultra-small crevices promotes the settlement of microorganisms naturally existing in the oral environment and thereby locally depleting the amount of oxygen changing the pH, resulting in intensification of the corrosion processes.

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